Argonne National Laboratory

EXAMINATION OF IRRADIATED Ag-In-Cd ALLOYS

by

C. F. Reinke

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C. F. Reinke

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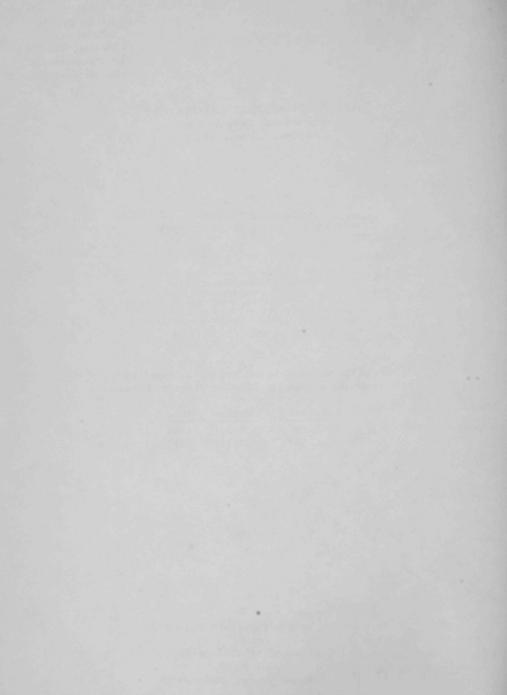


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EXAMINATION OF IRRADIATED Ag-In-Cd ALLOYS

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ABSTRACT

Extruded cast and extruded powder specimens of Ag-15w/oIn-5w/oCd alloy, plated with 25 μ of nickel or 25 μ each of copper plus nickel, were irradiated for 47 effective full-power days at approximately 300°C in a lattice position of the Engineering Test Reactor. The extruded cast alloys exhibited 0.2% yield strengths, ranging from 114 to 140 kg/ cm2 in the unirradiated condition, and 96 to 150 kg/cm2 after irradiation. The percent elongation and reduction in area in both cases normally ranged from 50 to 60%. The 0.2% yield strength for the extruded powder alloys ranged from 190 to 228 kg/cm2 in the unirradiated condition, and 214 to 242 kg/cm² after irradiation. There was a noticeable improvement in both the percent elongation and reduction in area of the extruded powder specimens, the postirradiation values being approximately twice the unirradiated values of 10%.

Recrystallization and grain growth occurred in all specimens during irradiation. The ASTM grain size on the extruded cast specimens changed from 7 to 4-5.5. Hardness measurements of the extruded cast specimens indicated that softening had occurred. Unirradiated material had DPH values ranging from 55 to 76, with corresponding values after irradiation of 36 to 52.

Metallographic examinations indicated that the microstructures had remained a single phase during irradiation.

INTRODUCTION

At present, the only elements that have been used extensively as the absorber material in power-reactor control rods are boron and hafnium. Neither material is ideal, but for different reasons. The main disadvantage of boron is the $B^{10}(n,\alpha)Li^7$ reaction, which introduces two new atoms into the

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specimens forther irradiation. The ASTM grain size on the extruded cast speciments changed from 7 to 4-5.5. Hardwest cast speciments of the extruded cast speciments indicated that spitching had occurred. Unirradiated material had DPH values ranging from 57 to 75, with corresponding values after irradiation of 35 to 75.

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At present, the only elements that have been used extensively as the absencer majorist in power residue. Souther majorist in an arm disadvantage Maither majorist ideal, but for different retroups. The main disadvantage of boron is the in (n. c) is reaction, which introduces two new atoms into the

lattice. Each atom is larger, and its properties differ from those of the parent boron atom and the matrix in which the boron is usually incorporated. For high-flux, long-life cores, radiation damage can be expected to be significant, and thus the suitability of boron and boron-containing materials is questionable. The use of hafnium produces a rod possessing desirable properties and long life. However, the drawback to the use of hafnium is that it is not readily available and is expensive. Considerable time and effort have been devoted to the development of low-cost, readilyavailable materials that would combine long-time reactivity worth, good mechanical strength and ductility, irradiation stability, and corrosion resistance. One such potential material which has received attention is the ternary alloy of Ag-15w/oIn-5w/oCd.(1,2) This report presents information on the stability and change in mechanical and physical properties of nickel and copper-plus-nickel plated specimens of the alloy after an irradiation of 47 effective full-power days at approximately 300°C in a lattice position of the Engineering Test Reactor. Specimen fabrication and irradiation were conducted by the WAPD Division of Westinghouse Electric Corporation. The postirradiation examination and evaluation were conducted at the Lemont site of Argonne National Laboratory.

FABRICATION

The fabrication procedures discussed in some detail in reference l are believed to be representative of those used to produce the test specimens. The basic steps, obtained from the reference, are outlined below for both the extruded cast and extruded powder alloys used in the irradiation studies. The data are tabulated in Table I.

Table I SPECIMEN DATA

| Specimen Series | Fabrication History | Preparation of Surface for Plating | Type of Plating ^(a) | Vacuum Anneal after Plating |
|--------------------|---|---------------------------------------|-----------------------------------|--------------------------------|
| CR-6-A | Induction-melted, cast, and extruded at 600°C. | Cleaned | Ni | 1 hr at 550°C |
| CR-6-B | Induction-melted, cast, and extruded at 600°C. | Etched | Ni | 1 hr at 550°C |
| CR-6-C&D | Induction-melted, cast, and extruded at 600°C. | Etched | Cu and Ni | 1 hr at 550°C |
| PCR-4-E | Induction-melted, atom- ized, hot-compacted, and extruded at 700°C. | Etched | Ni | 2 hr at 600°C |
| PCR-4-H | Induction-melted, atom- ized, hot-compacted, and extruded at 700°C. | Etched | Cu and Ni | 2 hr at 600°C |

⁽a) Nickel plate was 25 μ thick. Copper plus nickel plate were each 25 μ thick.

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Extruded Cast Specimens

The alloys were prepared by induction melting in graphite crucibles under a protective covering of calcined coke. The ingots were bottom-poured directly from the melting crucibles into graphite molds. Just before extrusion, the ingots were homogenized for 4 hr at 600°C. The test specimens were cut from full-size, extruded, control rods and machined to final dimensions. The machined specimens were then chemically etched and plated with either 25 μ of nickel, or 25 μ each of copper plus nickel. After plating, the specimens were given a 1-hr vacuum anneal at 550°C. The purpose of the anneal was to recrystallize the nickel deposit, provide metallurgical bonding between the plate and the base alloy, and enhance the ductility of the nickel plate.

Extruded Powder Specimens

Material of the desired chemical composition was prepared by melting in a graphite crucible under a protective covering of calcined coke. The melt was converted to powder by atomizing the molten alloy in a high-velocity water spray. Each powder particle thus produced had a very thin and continuous oxide film on its surface. The powder was hot-compacted in graphite molds at 600°C and extruded at 700°C to nearly 100% of theoretical density. The test specimens were cut from full-size control rods and machined to final dimensions. The machined specimens were then chemically etched and plated with either 25 μ of nickel, or 25 μ each of copper plus nickel. After plating, the specimens were given a 2-hr anneal at 600°C. The purpose of the anneal was the same as in the case of the extruded cast specimens. The very fine and uniformly-distributed dispersion of the oxide particles improved the mechanical strength of the alloy.

IRRADIATION

Five capsules were irradiated, each containing two tensile and eight metallographic specimens. The test specimens were placed between two slotted halves of a carbon-steel spacer, which was then fastened at each end with screws. Figure 1 is a pictorial drawing of the specimens and the capsule components. The assembled carbon-steel spacer containing the specimens was forced into an aluminum capsule having an interference fit, after which the capsule was welded shut in air. The soundness of the final closure weld was determined by externally pressurizing each capsule to $17.5~{\rm kg/cm^2}$ with helium and then immersing it in alcohol to check for leaks. As a final check, the capsules were corrosion-tested for $3\frac{1}{2}$ days at $170^{\circ}{\rm C}$.

The capsules were irradiated in the F-8 lattice position of the Engineering Test Reactor in Idaho from October 5, 1958 to December 29, 1958, for a total of 47 effective full-power days. (The Engineering Test Reactor operates at a power level of 175 MW.) Since the irradiation capsules were

The alloys were prepared by induction melting in graphite cruciples under a protective sovering of calcined coles. The lagots were bottom-poured directly from the mening crucibles into graphite molds. And loctors extra aion, the ingols were acmangenized for a int at 600°C. This less specimens were cut from fall-east, extruded, control rode and machined to final dimensions. The machined apacitmens were then chemically entited and placed with either 25 p each of copper plus michol. After plating, the appendix were given a need a 1-br vacuum armest at \$20°C. The purpose of the amendives in a received depends, provide metallurated bonding between the plate and the base alloy, and otherce the ductibity of the nickel plate.

Estimated Powder Specimens

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water agray. Each pewder particle thus produced had a very this and continnous oxide film on its surface. The powder was hot-compacted in graphite
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The test specimens were cut from full-nice control rods and machined to
final dimenations. The machined specimens were than chemically strined and
plated with either 25 to of nickel, or 25 to sach of copper plus mixed. After
plating, the specimens were given a 5-hr anneal at 500°C. The purpose of the
antical was the same as in the case of the extruded cast specimens. The very
that and uniformly-distributed dispersion of the oxide particles improved the
mechanical strongth of the alloy.

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Five capsules were irradiated, each containing live tensits and eight metallographic spectmens. The test spectmens were placed between two contents beloved helpes of a carbon-steel spacer, which was then revised at gack end with access. Figure 1 is a pictorial drawing of the openimens and the capsulated components. The assembled carbon-steel spacer containing the specific mens was forced into an aluminum capsule having an interference iit, intervention the capsulate was welded what in sir. The soundness of the final closure wall was determined by externally pressurising each capsule to 17.5 by femily with helium and then immersing it in alcohol to check for lease. As a final liberty, the capsules were correston-tested for 34 days at 170°C.

The capsules were irradiated to the F-8 lattice position of the Englancering Test Reactor is identificated Cataber 5, 1958 to December 29, 5958, for a total of 97 effective full-power days. (The Engineering Test Reactor operates at a power level of ITS MW.) Since the irradiation capsules work.

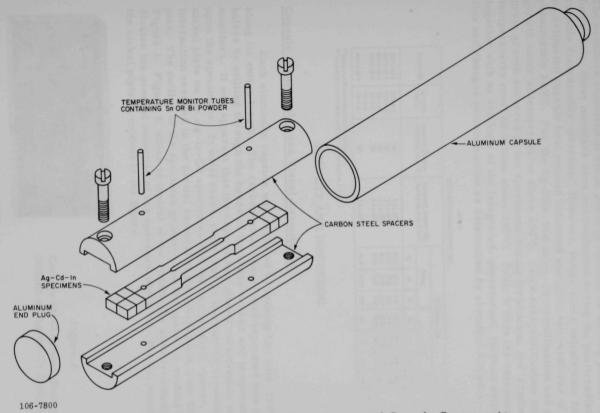
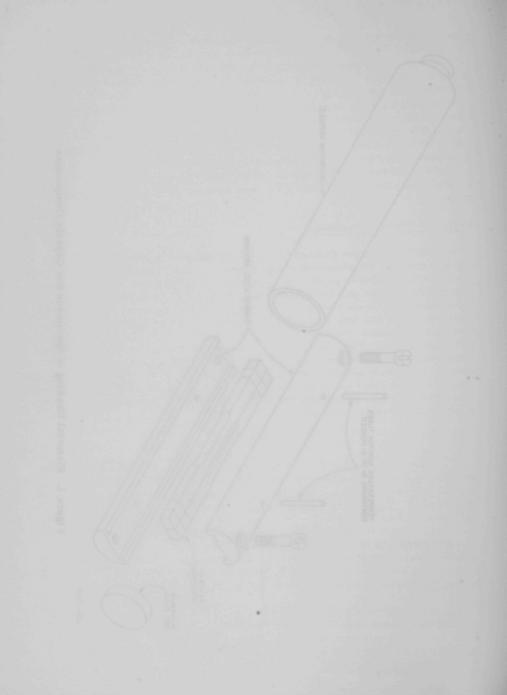


Figure 1. Pictorial Drawing of Specimens and Capsule Components



not instrumented with thermocouples, temperature monitors were included. The monitors consisted of metal powders with known melting points. Unfortunately, these monitors were not recovered during the postirradiation capsule disassembly operation. However, temperature calculations based on estimated capsule heat outputs indicated specimen temperatures of approximately 300°C. For the Ag-15In-5Cd alloy, recrystallization and grain growth occur at temperatures above 200°C. Since recrystallization and grain growth occurred in the specimens during irradiation, the irradiation temperatures must have been above 200°C. Table II lists the specimens, together with an estimate of the integrated, unperturbed, thermal neutron flux and changes in composition as determined by chemical analysis.

Table II
SPECIMEN IRRADIATION HISTORY

| | | | | | | Com | position, | w/o | | |
|--|--|--|--|----------------------------------|----------------------------------|------------------------------|----------------------------------|----------------------------------|------------------------------|------------------------------|
| Capsule No. | Specimen Series | Estimated Specimen Irradiation Temp, °C | Integrated, Unperturbed, Thermal Neutron Flux ^(a) | | Before | | | Afte | r | |
| | Series | Tradiation temp, | 111011111111111111111111111111111111111 | Ag | In | Cd | Ag | In | Cd | Sn |
| WAPD 44-1 WAPD 44-2 WAPD 44-3 WAPD 44-4 | PCR-4-E PCR-4-H CR-6-B CR-6-C | 300 300 300 300 300 | 1.2 × 10 ² 1 1.5 × 10 ² 1 1.7 × 10 ² 1 1.6 × 10 ² 1 | 80.23 80.75 80.47 80.08 | 15.11 15.16 14.86 14.82 | 4.66 4.09 4.67 5.10 | 79.23 78.36 78.36 78.65 | 14.56 14.72 13.36 14.25 | 5.66 6.48 6.79 6.53 | 0.55 0.44 1.45 0.55 |
| WAPD-44-5 | CR-6-D CR-6-A | 300 | 1.0 x 10 ²¹ | 80.65 | 14.72 | 4.63 | (P) | (P) | (P) | (b |

(a)Based on ETR-advertised flux for the position.
(b)The analyses contained an unknown source of error.

RESULTS AND DISCUSSION

Capsule Disassembly and Visual Examination

Each aluminum capsule was removed by making two cuts, 180° apart, along its entire length. The carbon-steel spacer was separated into its two halves by milling through the heads of the brass screws and temperature monitors. It was apparent that the capsule had placed considerable restraint upon the specimens. In most cases, there was an interaction between the nickel plate on the Ag-In-Cd specimens and the carbon-steel spacer. This interaction resulted in the partial removal of the nickel plate from the samples. The outline of the specimen geometry on the spacer is evident in Figure 2. Figure 3, which is typical of the specimens after irradiation, indicates the general condition of the specimen surfaces. Partial removal of the nickel plate is evident in the figure.



Figure 2

Carbon-Steel Spacer Showing

Outline of Ag-In-Cd Specimens



Figure 3

Ag-In-Cd Specimen after Irradiation.

Note partial removal of nickel plating.

Dimensional Measurements

Tables III and IV compare the pre- and postirradiation dimensions of the specimens from capsules WAPD-44-3 and WAPD-44-5. Figure 4 shows the locations at which the measurements were made. Since the precision of the measurements was 25 μ , the data indicate that no measurable change had occurred in the samples. This was not surprising, as the carbon-steel spacer and aluminum capsule placed considerable restraint upon the specimens. Because of this restraint, the significance of the dimensional data was questionable. Since this would also be true of the dimensional data from the other capsules, no further dimensional measurements were made.

Table III
PRE- AND POSTIRRADIATION DIMENSIONS ON METALLOGRAPHIC SPECIMENS

| | | | | | | Dim | ensions, cm | (a) | | | |
|-----------|--|-------------|----------------|-------|-----|-------|-------------|--------|-------|-------|---|
| Capsule | Series | Sample No. | | A | | | В | | | С | |
| Capsule | | | Pre | Post | Δ | Pre | Post | Δ | Pre | Post | Δ |
| | | | 0.775 | 0.777 | - | 0.576 | 0.574 | | 0.653 | 0.655 | - |
| WAPD 44-3 | CR-6-B | B-1 | 0.775 | 0.775 | | 0.574 | 0.576 | - | 0.650 | 0.653 | - |
| | | B-2 | 0.775 | 0.775 | | 0.579 | 0.576 | - | 0.653 | 0.653 | - |
| | S. Lake | B-3 | 0.775 | 0.772 | - | 0.576 | 0.574 | - | 0.653 | 0.650 | - |
| | | B-4 | 0.772 | 0.772 | - | 0.576 | 0.574 | - | 0.653 | 0.653 | - |
| | | B-7 | 0.772 | 0.770 | - | 0.574 | 0.572 | | 0.650 | 0.648 | - |
| | | B-8 | 0.772 0.775 | 0.775 | - | 0.576 | 0.574 | - | 0.653 | 0.650 | - |
| | | B-9 B-10 | 0.772 | 0.772 | - 0 | 0.576 | 0.576 | 100 | 0.650 | 0.650 | |
| | The state of the s | | 0.762 | 0.764 | - | 0.576 | 0.576 | - | 0.645 | 0.645 | |
| WAPD 44-5 | CR-6-A | A-1 | | 0.764 | | 0.579 | 0.576 | - | 0.650 | 0.648 | |
| | | A-2 | 0.762 | 0.759 | | 0.572 | 0.572 | - | 0.640 | 0.638 | |
| | | A-3 | 0.759 | 0.762 | | 0.582 | 0.576 | -0.006 | 0.645 | 0.645 | |
| | | A-4 | 0.762 0.757 | 0.759 | | 0.576 | 0.576 | - | 0.645 | 0.645 | |
| | 1 | A-7 | 0.754 | 0.752 | - | 0.566 | 0.566 | - | 0.638 | 0.635 | |
| | | A-8 | | 0.759 | | 0.579 | 0.579 | - | 0.648 | 0.648 | 1 |
| | Wand of | A-9 A-10 | 0.757 | 0.757 | | 0.569 | 0.572 | - | 0.638 | 0.638 | 1 |

(a) See Figure 4 for dimensional code used for reporting sample measurements. The preirradiation measurements were taken with a ball micrometer and are accurate to ±0.0013 cm.

The postirradiation measurements were taken with a ball micrometer and are accurate to ± 0.003 cm.



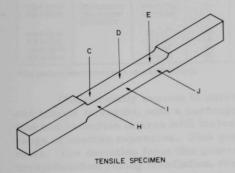
Table IV

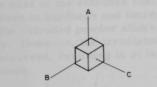
PRE- AND POSTIRRADIATION DIMENSIONS ON TENSILE SPECIMEN:

| | | | | | 1 | Dimensions, cm | (a) | 1.0000 | |
|-------------|--------|------------|------------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Capsule No. | Series | Sample No. | | | | Location | | | |
| | | | | С | D | E | Н | 1 | J |
| WAPD 44-3 | CR-6-B | B-5 | Pre Post A | 0.478 0.478 | 0.478 0.475 | 0.478 0.475 | 0.569 0.569 | 0.569 0.569 | 0.566 0.569 |
| | | B-6 | Pre Post Δ | 0.480 0.478 | 0.478 0.475 | 0.478 0.475 | 0.569 0.566 | 0,569 0,566 | 0.569 0.566 |
| WAPD 44-5 | CR-6-A | A-5 | Pre Post Δ | 0.467 0.465 | 0.462 0.460 | 0.465 0.465 | 0.561 0.559 | 0,561 0,559 | 0.561 0.559 |
| | | A-6 | Pre Post A | 0.460 0.457 | 0,460 0,460 | 0.462 0.462 | 0.556 0.554 | 0.556 0.554 | 0.554 0.554 |

(a) See Figure 4 for dimensional code used for reporting sample measurements. The preirradiation measurements were taken with a ball micrometer and are accurate to ±0.0013 cm.

The postirradiation measurements were taken with a ball micrometer and are accurate to ±0.003 cm.





METALLOGRAPHIC SPECIMENS

106-7799

Figure 4. Dimensional Code Used for Reporting Specimen Measurements

Tensile Tests

The results of the pre- and postirradiation tensile tests are tabulated in Table V. Since it was known that the mechanical properties of the extruded, coarse-grained specimens varied with the strain rate, all tensile tests were made at a constant strain rate of 0.127 cm/min. The 0.2% yield and ultimate tensile strength of both the extruded cast and extruded powder alloys did not change appreciably under the conditions of the irradiation. The extruded cast specimens exhibited 0.2% yield strengths and ultimate tensile strengths of 114 to 140 kg/cm² and 271 to 324 kg/cm², respectively, in the unirradiated condition with corresponding values after irradiation of 96 to 150 kg/cm² and 283 to 302 kg/cm². The percent elongation and reduction in area in both cases normally ranged from about 50 to 60%. The 0.2% yield strength of the extruded powder specimens was higher than the extruded cast alloys and ranged from 190 to 228 kg/cm² in the unirradiated

condition, and from 214 to 242 kg/cm² after irradiation. The ultimate tensile strengths of the extruded cast and extruded powder specimens were comparable in both the unirradiated and irradiated condition. Ultimate tensile strengths of the extruded powder specimens ranged from 273 to 337 kg/cm²

condition, and from 214 to 242 bare after avadation, 21) a climate five all

before irradiation, and from 292 to 325 kg/cm² after irradiation. There was a noticeable improvement in the percent elongation and reduction in area of the extruded powder specimens, the postirradiation values being approximately twice the unirradiated values of 10%.

Table \(\times \)

ROOM-TEMPERATURE TENSILE PROPERTIES OF IRRADIATED Ag-15w/oIn-5w/oCd ALLOY SPECIMENS

| Designation | Fabrication History | Integrated, Unperturbed, Thermal Neutron Flux | Irradiated Temp, °C | 0.2% Yield ^(a) Strength, kg/cm ² | Ultimate ^(a) Tensile Strength, kg/cm ² | Elongation, | Reduction in Area, % |
|--|---|---|---|--|--|----------------------------------|----------------------------------|
| CR-6-A(A-5) CR-6-B(B-5) CR-6-D(D-5) CR-6-D(D-6) | Extruded cast alloy, annealed 1 hr at 550°C | Unirradiated Unirradiated Unirradiated Unirradiated | : | 137 120 114 140 | 292 271 300 324 | 45 56 55 56 | 45 51 56 50 |
| CR-6-A(A-5) CR-6-A(A-6) CR-6-B(B-5) CR-6-B(B-6) CR-6-C(C-5) CR-6-D(D-6) | | $\begin{array}{c} 1.0 \times 10^{21} \\ 1.0 \times 10^{21} \\ 1.7 \times 10^{21} \\ 1.7 \times 10^{21} \\ 1.6 \times 10^{21} \\ 1.6 \times 10^{21} \end{array}$ | 300 300 300 300 300 300 300 | 114 121 96 131 150 122 | 288 283 289 301 299 302 | 62 58 66 58 62 59 | 53 56 57 57 54 54 |
| PCR-4-E(A-5) PCR-4-H(D-6) | Extruded powder alloy, annealed 2 hr at 600°C | Unirradiated Unirradiated | : | 190 228 | 273 337 | 11 13 | 9 9 |
| PCR-4-E(E-5) PCR-4-E(E-6) PCR-4-H(H-5) PCR-4-H(H-6) | | 1.2 x 10 ²¹ 1.2 x 10 ²¹ 1.5 x 10 ²¹ 1.5 x 10 ²¹ | 300 300 300 300 | 214 242 225 226 | 318 325 292 307 | 17 19 23 20 | 24 30 22 14 |

(a) The specimens were tested at a strain rate of 0.127 cm/cm-min.

One normally expects to observe a marked increase in both yield and tensile strengths, with a corresponding decrease in the percent elongation and reduction in area with increasing neutron exposure over a wide range of neutron exposures. This general trend did not hold for these specimens. The deviation from this general trend was thought to be due to recrystallization during irradiation, thus annealing-out any induced hardening, and in some cases even softening the alloy below the unirradiated condition. In the case of the extruded cast alloys, this was substantiated by the general decrease in hardness and increase in grain size of the irradiated specimens. For the extruded powder alloys, the hardness values did not change appreciably. However, the irradiated microstructures indicated recrystallization had occurred, resulting in at least a partial loss of the oriented as-fabricated structure.

The nickel plating on the tensile specimens cracked during testing. It was most pronounced on the extruded cast specimens. As shown in Figure 5, the plating not only cracked but also separated from the base alloy at the edges of the specimen. Figure 6 is typical of the extruded powder specimens. The nickel plate exhibited considerably less cracking and separation from the base alloy. No difference in behavior was noted between the plating on the irradiated and unirradiated specimens. The difference in behavior between the plating on the extruded cast and extruded powder alloys was believed to be due to the greater percent elongation and reduction in area exhibited by the extruded cast specimens.

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Figure 5
Separation of Nickel
Plating from Base Alloy
on Extruded Cast Tensile Specimen

EI-2476

3**X**

Figure 6

Cracks in Nickel Plating on Extruded Powder Tensile Specimen



EI-797

3X

Grain Size and Hardness Measurements

Grain-size determinations and hardness measurements were made on both unirradiated and irradiated specimens. The results are tabulated in Table VI. Recrystallization and grain growth occurred on the extruded

 $\label{eq:table_VI} Table\;VI$ DPH HARDNESS AND GRAIN SIZE OF Ag-15w/oIn-5w/oCd ALLOY SPECIMENS

| Designation | Irradiation Temp, °C | DPH Values(a) | | ASTM |
|--|-------------------------|---------------|-----------------------|---------------|
| | | Range | Average Value | Grain Size(d) |
| Extruded cast alloys | Unirradiated | 55 to 78 | 66 ± 8 ^(b) | 7 |
| CR-6A, B, C, & D Extruded cast alloys | 300 | 36 to 55 | 46 ± 8(c) | 4 to 5.5 |
| CR-6A, B, C, & D Extruded powder | Unirradiated | 87 to 95 | 90 ± 2(e) | 1600 |
| alloys PCR-4-E & H Extruded powder | 300 | 81 to 100 | 92 ± 6 ^(f) | |
| alloys PCR-4-E & H | | | Section 1 | |

(a) A 1-kg load was applied.

(b)A total of 30 measurements were made.

(c)A total of 9 measurements were made.

(d) As determined by ASTM designation E112.63, 1963 Revision.

(e) A total of 18 measurements were made. (f) A total of 12 measurements were made.



cast specimens during irradiation. The ASTM grain size of the unirradiated, extruded cast specimens was 7.0. Corresponding postirradiation values ranged from 4 to 5.5.

The DPH values on the unirradiated, extruded cast alloys ranged from 55 to 78, with an average value of 66 and a standard deviation of ± 8 DPH units. After irradiation, the values ranged from 36 to 55, with an average value of 46 and a standard deviation of ± 8 DPH units.

Table VII lists the results of a Knoop hardness survey conducted on specimens of the extruded cast alloy. In general, the measurements indicate that areas near the specimen surface were slightly harder than interior areas. One specimen exhibited an area, 0.1 cm in from the surface of the alloy, that was significantly harder than the surrounding areas. The reason for this localized area of increased hardness is not known.

Table VII

KNOOP HARDNESS SURVEY OF
IRRADIATED Ag-15w/oIn-5w/oCd ALLOYS

| | Irradiation | Knoop Hardness(a) | | |
|----------------------|-------------|-------------------|------------------|--|
| Specimen Designation | Temp, °C | Location, cm(b) | Values | |
| Extruded cast | 300 | Surface | 13.1 | |
| alloy CR-6A | | 0.025 | 11.2 | |
| | | 0.050 | 10.5 | |
| | | 0.075 | 10.6 | |
| | | 0.100 | 10.5 | |
| Extruded cast | 300 | Surface | 11.4 | |
| alloy CR-6B | | 0.025 | 10.2 | |
| | | 0.050 | 8.8 | |
| | | 0.075 | 8.9 | |
| | | 0.100 | 10.5, 11.2, 13.1 | |
| | | 0,125 | 8.7 | |

⁽a)A 200-g load was applied.

For the extruded powder alloys, the hardness values did not change appreciably with irradiation. The DPH values on the unirradiated, extruded powder alloys ranged from 87 to 95, with an average value of 90 and a standard deviation of ± 2 DPH units. After irradiation, the values ranged from 81 to 100, with an average value of 92 and a standard deviation of ± 6 DPH units.

⁽b) Measurements were made at the surface of each core alloy, and then at 0.025-cm intervals towards the specimen center.

cast spectroes during arradiation. The ASTM grows are of the uniprodiated. carreded cast specimens was 7.0. Corresponding postiried attack with use ratiged from M. My.S. S.

restricted values on the universalisted, educated usi alloys ranged from 50 to 90, with an estandard deviation of a north units. After freedition, the subservanged from 50 to 95, with an extense value value of 40 and a standard deviation of se OFM units.

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KNOOP HARDNESS SURVEY OF ERADIATED AS ISW/ola-Sw/sca alliqys

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Messurements were incident the surface of each Lore alloy, and then:

For the extruded purely alloyer the hardness values difficit change appreciately with irradiation. The Toff values on the unirrediated, extraded provider allows ranged from \$7 to 05, with an average value of 90 and a standard deviation of 20 DTH units. After irradiation, the values ranged from \$1 to 100, with an average value of 92 and a s'andord deviation of 10 DTH units.

The irradiated microstructures of the extruded powder alloys indicated recrystallization had occurred during irradiation, resulting in at least a partial loss of the oriented as-fabricated structure.

Metallographic Examination

The absorption of neutrons by the isotopes of the Ag-In-Cd alloy leads to nuclear transformations. The majority of the transformed silver goes to cadmium, the indium to tin, and the cadmium to another isotope of cadmium. There is a limit to the amount of tin that can be dissolved in the alloy. It is anticipated that after extended operation at high power levels, the limit of solubility of tin will be reached and any further production of tin will result in its rejection from solid solution and the formation of a second-phase precipitate. This precipitate may be especially prevelant in the more highly burned-out surface layers of the specimens. The pre- and postirradiation microstructures are compared in Figure 7. The microstructures indicated that the alloys had remained single-phase during irradiation. There was no second phase present, even in the specimen that analyzed 1.5% tin after irradiation.

The metallographic specimens were mounted in Bakelite and ground to a 600 grit finish using silicon carbide papers. The specimens were prepared by alternately polishing with Linde A compound on microcloth and swab-etching with a solution composed of one part stock solution and nine parts water. The stock solution contained $K_2Cr_2O_7$, NaCl, and H_2SO_4 in the ratio of 50/1/5, respectively. The specimens were swab-etched just before examination.

Burnup Analysis

One specimen from each capsule was chemically analyzed for the quantity of silver, indium, and cadmium present. The amount of tin was obtained by difference, noting that the atom fraction of indium before irradiation is equal to the sum of the atom fractions of indium and tin after irradiation. The results of these analyses, when compared with the unirradiated compositions, indicate the elemental burnout during irradiation. Table II lists the pre- and postirradiation compositions.

The specimens were prepared for analysis by dissolving them in nitric acid, and by diluting and cooling the solution. The solution was titrated with standard ammonium thiocyanate solution to determine the amount of silver present. The silver thiocyanate precipitate was washed and filtered, and the filtrate was analyzed for indium and cadmium. The cadmium was analyzed colorimetrically, and the indium by spectrochemical methods.

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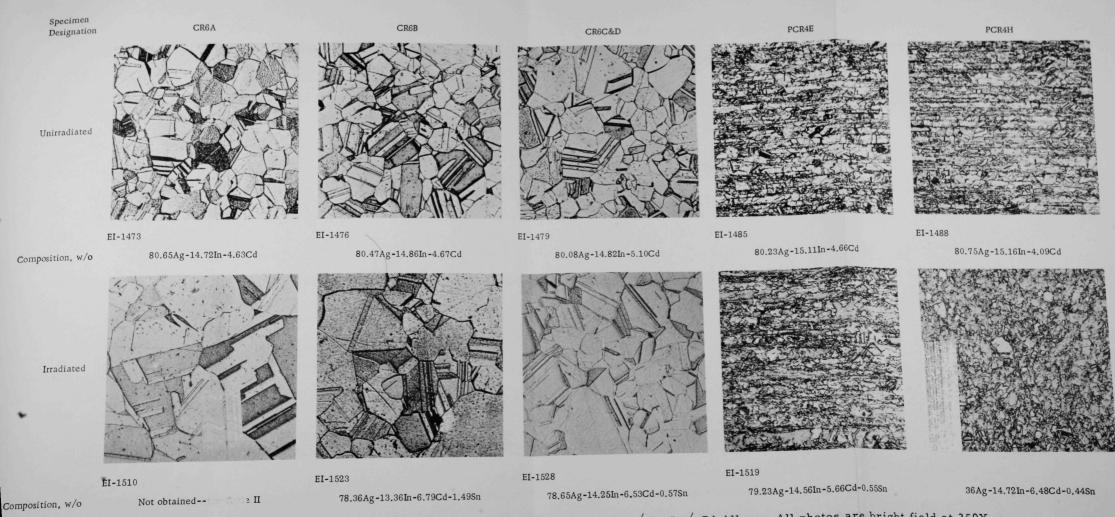


Figure 7. Communison of Pre- and Postirradiation Microstructures on Ag-15w/oIn-5w/oCd Alloys. All photos are bright field at 250X.



CONCLUSIONS

- There was very little change in the 0.2% yield and ultimate tensile strength of extruded cast and extruded powder Ag-15w/oIn-5w/oCd alloy specimens irradiated to integrated, unperturbed, thermal neutron fluxes of between 1.0 and 1.7 x 10²¹ nvt at 300°C.
- 2. The extruded cast alloys exhibited 0.2% yield strengths ranging from 114 to 140 kg/cm² in the unirradiated condition, and from 96 to 150 kg/cm² after irradiation. The percent elongation and reduction in area in both cases normally ranged from 50 to 60%.
- 3. The extruded powder alloys exhibited 0.2% yield strengths ranging from 190 to 228 kg/cm² in the unirradiated condition, and from 214 to 242 kg/cm² after irradiation. There was a noticeable improvement in both the percent elongation and reduction in area with irradiation, the postirradiation values being approximately twice the unirradiated values of 10%.
- Recrystallization and grain growth occurred in all specimens during irradiation.
- The ASTM grain size on the extruded cast specimens changed from 7 to 4-5.5.
- The extruded cast specimens softened during irradiation. Unirradiated material had DPH values ranging from 55 to 78, with corresponding values after irradiation of 36 to 55.
- 7. There was little overall change in the hardness of the extruded powder alloys. Unirradiated material had DPH values ranging from 87 to 95, with corresponding values after irradiation of 81 to 100.
- 8. The metallographic examinations indicated that the microstructures had remained single-phase during irradiation.

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-- Specimen fabrication, capsule irradiations, preirradiation data

- W. D. Jackson, R. P. Enders, and W. A. Ahrens
- -- Postirradiation data collection

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- There was very little change in the 0.2% yield and ultimate tensile drampin of extraoded coast and extraded powder Ag-15w/oln-5w occaller apprishments translated to integrated, unportunited thermal neutron there at 1.0 and 1.7 x 10²¹ not at 1000c.
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 Specimes (abrication, paper sule irradiations, prefrage distrion dala

> W. D. Jackson, R. P. Enders, and W. A. Ahrens

Postirentiation daily

R. W. Bane and J. P. Faris

-- Burnup analyses

R. Carlander, W. A. Ahrens, and W. C. Kettman

-- Metallography

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W. Blane and J. P. Paris.

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